Current Loop Has 5-kV Isolation

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By using an AD7245A DACPORT, a linear optoisolator, and a discrete V-I converter to control loop current, a 4-to-20-mA isolated current loop may be digitally controlled across a 5-kV barrier *(see the figure)*.

The complete circuit exhibits excellent linearity between the digital input word and the isolated analog output current. Up to 11-bit performance is achievable with 12-bit monotonicity. The AD7245A contains a 12-bit digital-to-analog converter, an output amplifier, and a +5-V reference. Although the reference is used internally for the DAC, it can also be used for external biasing.

The IL300 optocoupler contains a single LED and two identical but isolated photodiodes. Both diodes receive equal irradiation from the LED. Therefore, by biasing each photodiode with a similar voltage, an identical current will flow through each. Because the relationship between both the LED and photodiode currents is nonlinear, it's necessary to use a feedback loop that monitors the current flowing through one of the photodiodes and then servos the LED drive current when needed.

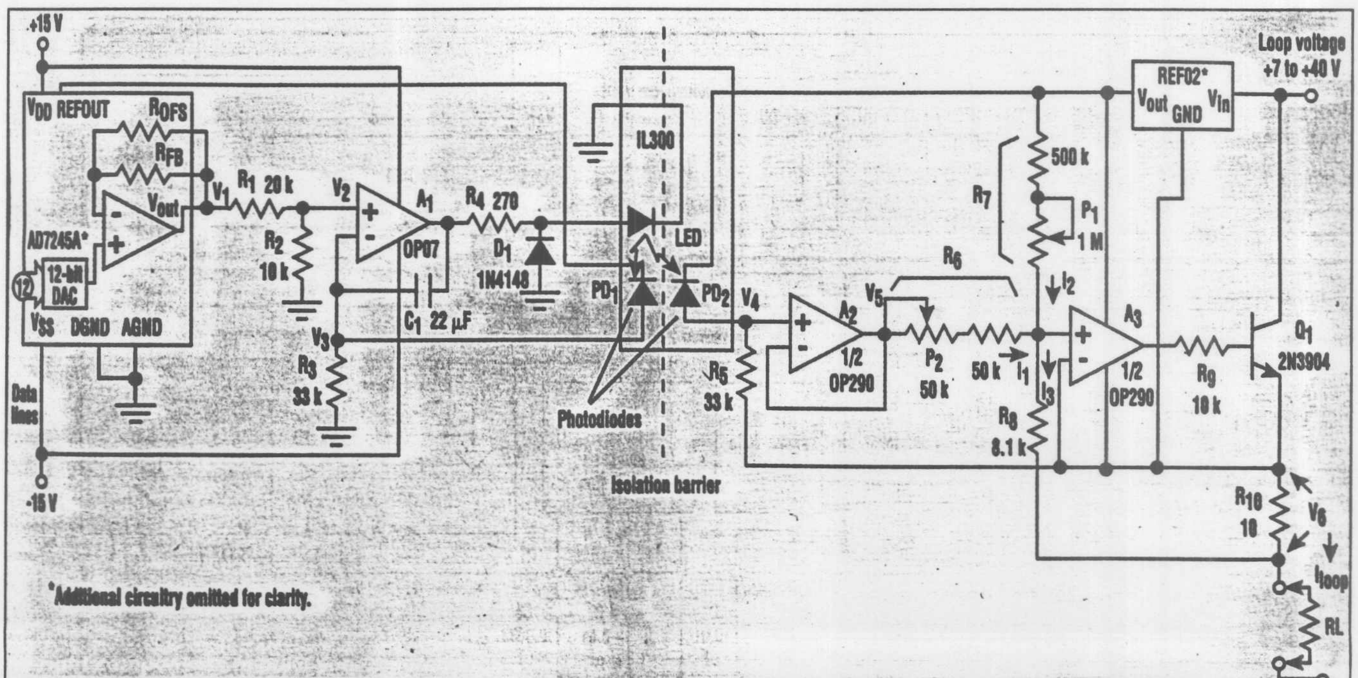
The DACPORT is configured to operate in the 0-to-+5-V output range. This output swing (V_1) is attenuated by R_1 and R_2 to give 0 to +1.666 V at the noninverting amplifier input (V_2).The negative feedback loop, which consists of the LED and one of the photodiodes in the IL300 (PD_1), ensures that the voltage (V_3) at the inverting terminal of the amplifier (A_1) will be at the same potential as the voltage at the noninverting terminal.

The current flowing through the photodiode will be very small, and more importantly, the change in current flow for a 1 LSB change in DAC code will be negligible (12 nA). Therefore, it's important that a highly accurate and stable voltage reference source is used as a bias supply. The +5-V reference output on the AD7245A provides this bias.

A similar current will flow through the second photodiode, generating an equivalent voltage across resistor R_5. Again, it's essential that an accurate and stable voltage reference bias is used so that any current variations are minimized. In this case, the REF02 supplies a stable +5-V bias voltage.

The isolated output voltage (V_4) is buffered by A_2. V_4 controls a V-I converter formed using A_3 and Q_1.

The buffered output voltage (V_5) ranges between 0 and +1.666 V, de-



Loop current can be digitally controlled with this isolated 4-to-20-mA current-loop controller, which contains a 12-bit DACPORT, a linear optocoupler, and a discrete V-I converter. The circuit has 5 kV of optical isolation between the controller and the current loop.

pending on the code applied to the DAC. This is transformed into a loop current by A_3 and transistor Q_1. The loop current (I_{loop}) is monitored with a 10-Ω sense resistor (R_{10}). A low resistance value minimizes the voltage dropped across it and allows the loop to operate with low loop supply voltages. Q_1 is connected as an emitter follower in a feedback circuit that controls the current flowing in the loop. The feedback circuit forces both A_3 amplifier inputs to the same potential. Consequently, the voltage across the sense resistor (V_6) is equal to the voltage across the feedback resistor (R_8). Because no current flows into the amplifier inputs, current I_3 flowing through R_8 must equal the sum of the currents flowing through R_6 and R_7. I_{loop} is therefore controlled by I_1 and I_2.

I_2 sets up a 4-mA loop-current offset, while I_1 is controlled by the DACPORT to a further 0 to 16 mA. The loop current is:

$I_{loop}(mA) = 4 + 16(D)$

where D is a fractional representation of the digital word applied. It may be programmed between 0 and 4095/4096.

The circuit contains an offset and full-scale adjustment facility. This offset potentiometer (P_1) should be trimmed until a 4-mA current is measured flowing in the loop. This is done with all 0's loaded to the DAC. With all 1's loaded to the DAC, the gain-adjusting potentiometer (P_2) should be trimmed until a current of 20 mA – 1 LSB (19.996 mA) is measured flowing in the loop. Note that 1 LSB of current is equal to 16/4096 mA = 3.9 μA.

Update by Scott Wayne and Michael Coln

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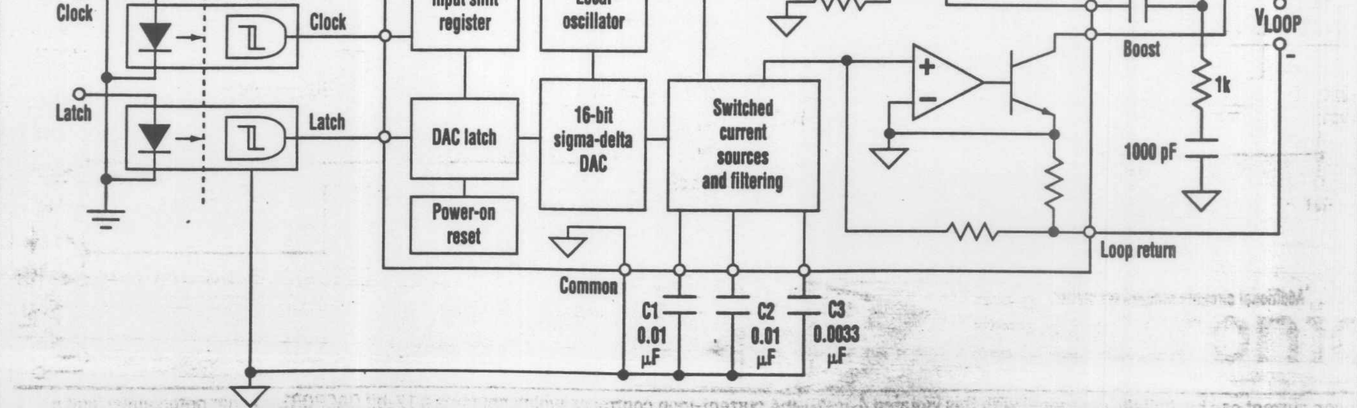
Despite the advent of several competing digital fieldbuses, 4- to 20-mA control loops are still widely used in industrial process control systems. Many available sensors and actuators are easy to understand and troubleshoot. Smart transmitters and communications protocols, such as the Highway Addressable Remote Transducer (HART) protocol, have kept of 4- to 20-mA systems popular. Isolation is sometimes required in intrinsically safe applications or due to noise, safety requirements, or distance.

The 1993 Idea for Design required four integrated circuits, a linear optocoupler, and a handful of discrete components *(see original figure)*. It also required a dc-dc converter (not shown) to provide isolated power for the DAC and op amp. Today, the entire function can be built with one IC and three digital optocouplers *(see updated figure)*. Also, the entire circuit is loop-powered, so the dc-dc converter isn't required.

The AD421 is a complete 4- to 20-mA DAC. It includes a selectable regulator that's used to power itself and other devices, so a REF02 isn't required. Its current-loop drive circuitry eliminates the OP-290s and discrete components. Because simple digital isolators are being used, the OP-07 and associated bias components can be discarded. The AD421 offers a precision reference that's available for external use, a programmable alarm current that can indicate transducer faults, and power-on reset.

It actually provides 16-bit resolution, rather than the 12 bits given by the AD7245A. The isolated lines are digital, so the full linearity of the converter is maintained. Maximum power consumption is 750 μA, leaving up to 3.25 mA to be used by any external circuitry, while still remaining loop-powered. The AD421 comes in a 16-lead, 0.3-in.-wide SOIC, minimizing pc-board area.



This updated version of the 1993 circuit for a current loop with 5-kV isolation needs only a single IC and three digital optocouplers.